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DATE: November 16, 2017

SUBJECT: SUMMARY OF REVIEW OF STUDY 287400: MONITORING OF SULFURYL FLUORIDE AND CHLOROPICRIN CONCENTRATIONS IN AMBIENT AIR AROUND RESIDENTIAL STRUCTURES DURING A BEETLE RATE FUMIGATION, AERATION AND POST-CLEARANCE

This memorandum summarizes the key results of the analysis of an exposure study in which Vikane® (active ingredient sulfuryl fluoride) was used in structural fumigations for powder-post beetles (Barnekow and Rotondaro, 2015). The study was conducted by the registrant Dow AgroSciences (DAS) using the revised version of the California Aeration Plan (CAP II, ENF 13-07, http://www.cdpr.ca.gov/docs/county/cacltrs/penfltrs/penf2013/2013007.htm) as the aeration procedure. The goal of the study was to investigate the effectiveness of CAP II to reduce human exposure during and after structural fumigations that were made using maximum application rates allowed by labels for the treatment of powder-post beetles. Prior studies were conducted at lower application rates allowed by labels under different aeration procedures and summarized by Cochran and DiPaolo (2006), Cochran (2010) and Beauvais (2013).

The Risk Management Directive (Gosselin, 2007) established mitigation targets for sulfuryl fluoride exposures in accordance with the reference concentrations (R_fC) identified in the Risk Characterization Document (Lim, 2006). The 24-hr time-weighted average (TWA) mitigation targets were as follows (Gosselin, 2007):

- 2.57 ppm for acute workers exposures;
- 0.12 ppm for acute exposures to residents and bystanders;
- 0.48 ppm for repetitive (1-2 weeks) worker exposures;
- 0.14 ppm for worker seasonal exposures;
- 0.04 ppm for worker chronic exposures.

In March 2017, Department of Pesticide Regulation (DPR) published a memorandum (Dong *et al*., 2017) establishing updated uncertainty factors and reference concentrations for exposures to sulfuryl fluoride for workers and residential bystanders (infants):

- 2.6 ppm 8-hr TWA acute R_fC for female workers;
- 0.41 ppm 24-hr TWA acute R_fC for residential bystanders;
- 0.13 ppm 8-hr TWA short-term (1-2 weeks) and chronic R_fC for female workers;
- 0.015 ppm 24-hr TWA short-term (1-2 weeks) and chronic R_fC for residential bystanders (Dong *et al*., 2017).

About 3% of the structural fumigations in California are done for treatment of powder-post beetles and death watch beetles. These fumigations require application rates of ten times (10X) the typical dry wood termite rate of 8 oz/1,000 ft^3, which is usually achieved by increasing the amount of sulfuryl fluoride up to 60 oz/1,000 ft^3 while simultaneously increasing the exposure time up to 72 hr (Beauvais, 2013).

The current study (Barnekow and Rotondaro, 2015) includes fumigation, aeration and post-clearance phases of three California single-family houses, and follows the general protocol of previous studies performed by DAS (Barnekow and Byrne, 2006; Barnekow, 2010). The major differences between this study and the previous studies were: (1) increased application rates for beetle treatment (40, 52 and 63 oz /1,000 ft^3 for the three individual homes, respectively, with mean application rate of 52 oz /1,000 ft^3); (2) increased holding time for fumigation phases (48-hours); (3) increased aeration time (approximately 21-hours); (4) fewer number of homes fumigated (three); and, (5) sulfuryl fluoride monitoring inside a neighboring house during the fumigation and aeration phases). This was done to better represent the exposure of persons residing in the vicinity of structures being fumigated with sulfuryl fluoride for powder-post beetles. The air sampling stations were located outside and inside of the fumigated houses. Time-weighted average sulfuryl fluoride samples were collected on activated charcoal absorption tubes positioned on masts at 150 cm (approx. 5 ft) above the ground or above the floor level, respectively, to simulate a person's breathing zone. Sulfuryl fluoride concentrations were monitored in the external perimeter of the fumigated houses (twelve air monitoring stations in total: eight samplers at 5 ft, and four samplers at 10 ft from the structure) and inside an adjacent home (two air monitoring stations in each) both during the fumigation phase (approximately 48-hours) and aeration phase (approximately 21-hours). Additionally, three air sampling stations were located in different rooms of the fumigated homes to measure the internal sulfuryl fluoride concentrations during the 48-hours following the aeration (post-clearance phase). The limit of detection (LOD) of the study was 1.75 µg. Samples with non-detects were replaced by 1/2 LOD. The field fortifications at three-spike levels, 15 µg, 100 µg and 1,000 µg, gave very similar recoveries with an average of 84% (standard deviation ± 5%). Unlike the previous DAS studies (Barnekow and Byrne, 2006; Barnekow, 2010), the sulfuryl fluoride concentrations presented in the current report were not corrected for fortification recoveries.

In the absence of personal air monitoring of workers performing fumigation tasks, previous studies have used sulfuryl fluoride data provided by stationary air sampler monitors inside and outside the fumigated homes (summarized in Cochran, 2010; Beauvais, 2013). In our analysis, we used the same approach to estimate worker exposures to sulfuryl fluoride during and after

powder-post beetle fumigations. Residential exposures were derived from sulfuryl fluoride readings provided by the stationary air samplers located inside the fumigated structures and inside the neighboring homes.

Based on the report of Barnekow and Rotondaro (2015), Table 1 summarizes the key results for occupational and residential exposures to sulfuryl fluoride during and after powder-post beetle fumigations. The raw data used to estimate the exposures presented in Table 1 were adjusted for 84% fortification recovery in this memorandum. Worker exposures were calculated in a manner similar to that described in (Cochran, 2010) and adjusted for the specifics of the study. In order to align the exposure estimates to the 8-hr TWA R_fCs in (Dong *et al*., 2017), the time spent at various work activities (see explanations in the table) was prorated from 10-hr workday or 4-hr workday for short-term and long-term exposures respectively (Cochran, 2010), to an 8-hr workday for all worker exposures. Residential bystander exposures were estimated from data provided by stationary air samplers inside and outside the fumigated homes. This approach was similar to Beauvais (2013), but adapted to the specifics of the study. In Beauvais (2013), for the lack of better data, the residential exposures in the vicinity of structures under fumigation and aeration were derived from readings of outdoor air samplers located at the perimeter of the fumigated home. In addition to perimeter sulfuryl fluoride samplers, Barnekow and Rotondaro (2015) located sampling stations inside the neighboring homes – providing more appropriate estimate of sulfuryl fluoride exposures to residents living near residential structural fumigations.

The results in Table 1 show that all occupational exposures are below the 8-hr TWA reference concentration values of 2.6 ppm for acute exposure (referenced in Table 1 as short-term exposure) and 0.13 ppm for long-term exposures (referenced in Table 1 as seasonal, annual and life-time exposures) as outlined in (Dong *et al*., 2017).

Among the residential bystander scenarios, the 24-hr TWA exposures of bystanders residing in adjacent homes to houses under beetle fumigation (48-hour holding period) exceeded the reference concentration of 0.41 ppm for the duration of the holding period (0-24 h and 24-48 h) (Table 1). Similarly, the 24-hr TWA exposure of residents reentering fumigated and aerated houses during the post-clearance period exceeded the reference concentration of 0.41 ppm for the duration of the monitoring period (data available for 0-24 h and 24-48 h) (Table 1). The exposures exceeding the R_fC values are marked in **bold** in Table 1.

Table 1. Estimated exposures (ppm) to sulfuryl fluoride (SF) for workers and residents, based on measured air concentrations of sulfuryl fluoride during and after powder-post beetle fumigations (Barnekow and Rotondaro, 2015). The raw data used to estimate the exposures were adjusted for 84% fortification recovery in this memorandum.

Exposure scenario [1]	Short-term exposure [2] (ppm)	Seasonal exposure [3] (ppm)	Annual exposure [4] (ppm)	Lifetime exposure [5] (ppm)
Fumigators	0.17 [6]	0.05 [7]	0.02	0.01
Tent crew	0.12 [8]	0.04 [9]	0.02	0.01
Fumigator, tent & clearance activity	0.15 [10]	0.04 [11]	0.02	0.01
Bystanders residing in adjacent structures during the first 24 hours of the fumigation phase (0-24 h), 24-hr TWA	**0.48** [12]			
Bystanders residing in adjacent structures during the second 24 hours of the fumigation phase (24-48 h), 24-hr TWA	**0.67** [13]			
Bystanders residing in adjacent structures during the aeration phase, 22-hr TWA	0.23 [14]			
Residents reentering aerated structures during the first 24 hours of post-clearance (0-24 h), 24-hr TWA	**1.14** [15]			
Residents reentering aerated structures during the second 24 hours of post-clearance (24-48 h), 24-hr TWA	**0.72** [16]			

[1] Worker exposures are calculated in a manner similar to that described in (Cochran, 2010). The equations, terms and definitions used in footnotes 6-11 were formulated in (Cochran, 2010) and adjusted for the specifics of the study. In order to align the exposure estimates to the 8-hr TWA worker R_fCs in (Dong *et al.* (2017)), the time spent at various work activities (see explanations below) was prorated from 10-hr workday for short-term exposures or 4-hr workday for long-term exposures (Cochran, 2010) to an 8-hr workday for both short-term and long-term exposures. 24-hr TWA residential bystander exposures are calculated in a manner similar to that described in (Beauvais, 2013) and adjusted for the specifics of the study. However, the exposures to residents living near house fumigations were estimated from sampling stations inside the neighboring homes rather than from perimeter readings at the fumigated home.

[2] Short-term exposure is exposure that lasts between one day and 7 days (Kwok, 2017). For workers one day is typically 8 hours, for residents it is 24 hours. Ordinarily, WH&S calculates the 95th percentile to estimate an upper-bound acute exposure to fumigants. This statistical approach assumes that each sampling station has an equal probability for capturing an unbiased sample of SF. However, outdoor air movement, such as breezes, can bias the samples. Consequently, in this evaluation the highest measured air concentration of SF at 5 feet was used to as the upper-bound SF concentration" (Cochran, 2010). Similarly to the approach in (Cochran, 2010), we used the highest recorded SF concentrations to derive the short-term exposure estimates.

[3] Seasonal exposure is exposure that lasts between one week and one year (Kwok, 2017). It is calculated as the mean measured SF air concentration in the respective location (see explanations below).

[4] Annual worker exposure is exposure that spans the course of the entire year. It is calculated by multiplying the

seasonal exposure by the number of days of SF use during the year, and amortizing it over 365 days (Cochran and DiPaolo, 2006). Cochran and DiPaolo (2006) analyzed the work patterns of three fumigation crews in California reported in Contardi and Lambesis (1996), and combined the data with that from U.S. Department of Labor to calculate the average number of days per year workers were engaged in particular fumigation jobs. The data in Table 5 in (Cochran, 2010) showed that on average, workers were engaged as fumigators 188 days per year: this was the mean value of the average number of days per year for the four fumigator jobs listed in Table 5 in Cochran and DiPaolo (2006). Tent crews were engaged 180 days per year (Table 5 in Cochran and DiPaolo, 2006). Here we assumed that fumigator, tent & clearance crew activities would be 184 days a year as the mean between the annual durations for fumigator crew and tent crew assignments.

[5] Worker lifetime exposure is exposure resulting from doing the same work for 40 years in a lifetime of 75 years (Cochran and DiPaolo, 2006). Lifetime exposure is calculated as annual exposure multiplied by 40 and divided by 75.

[6] Fumigators, short-term exposure:

- 8-hr TWA = (T_{fa} * [SF_1]) / 8, where:
- T_{fa} = Time spent in activities during the fumigation phase (Cochran, 2010) (2 hr);
- SF_1 = The highest measured, hourly sulfuryl fluoride concentration at 5 feet from the structure (Cochran, 2010) during the first sampling period of the fumigation phase (sampling event #1, House 1, sampling location NW-5 in (Barnekow, 2015)). The actual sampling time was 4.07 hours;
    - SF_1 = 2.775 ppm / 4.07 hr = 0.682 ppm.

[7] Fumigators, seasonal exposure:

- 8-hr TWA = (T_{fa} * [SF_1]) / 8, where:
- T_{fa} = 2 hr;
- SF_1 = Mean measured, hourly SF concentration at 5 feet from the structure (Cochran, 2010) during the first sampling period of the fumigation phase (sampling event #1, Houses 1-3, in (Barnekow, 2015)). The average duration of sampling event #1 was 4.08 hours;
    - SF_1 = 0.762 ppm / 4.08 hr = 0.187 ppm.

[8] Tent crew, short-term exposure:

- 8-hr TWA = (T_{tdo} * [SF_o] + T_{tdi} * [SF_i]) / 8, where:
- T_{tdo} = Time spent in take-down activities outside the fumigated structures (Cochran, 2010) (6 hrs);
- T_{tdi} = Time spent removing equipment from inside the structure after aeration (Cochran, 2010) (2 hr);
- SF_o = The highest measured, hourly sulfuryl fluoride concentration at 5 feet from the structure (Cochran, 2010) during the last sampling period of aeration (sampling event #12a, House 3, sampling location E-5 in (Barnekow, 2015)). This sample was <LOD and was replaced by 1/2 LOD before adjustment for field spike recovery. The actual sampling time was 6.8 hours;
    - SF_o = 0.0131 ppm / 6.8 hr = 0.0019 ppm.
- SF_i = The highest measured, hourly SF concentration in living areas inside the structure (Cochran, 2010) during the first 1-hr post-clearance period (sampling event #13, House 2, location Inside 1, in (Barnekow, 2015));
    - SF_i = 0.486 ppm / 1 hr = 0.486 ppm.

[9] Tent crew, seasonal exposure:

- 8-hr TWA = (T_{tdo} * [SF_o] + T_{tdi} * [SF_i]) / 8, where:
- T_{tdo} = 6 hr;
- T_{tdi} = 2 hr;
- SF_o = mean measured, hourly SF concentration at 5 feet from the structure (Cochran, 2010) during the last sampling period of aeration (sampling event #12a, Houses 1-3, in (Barnekow, 2015)). All samples were <LOD and were replaced by 1/2 LOD before adjustment for field spike recovery. The average duration of sampling event #12a was 7.7 hours;
    - SF_o = 0.0112 ppm / 7.7 hr = 0.0015 ppm.
- SF_i = mean measured, hourly SF concentration in living areas inside a structure during the first 1-hr post-clearance period (Cochran, 2010) (sampling event #13, Houses 1-3, in (Barnekow, 2015));
    - SF_i = 0.157 ppm / 1 hr = 0.157 ppm.

[10] Fumigator & clearance crew, short-term exposure:

- 8-hr TWA = (T_{fa} * [SF_1] + T_{tdo} * [SF_o] + T_{tdi} * [SF_i]) / 8 hr, where:
- T_{fa} = 1.2 hr;
- T_{tdo} = 2.4 hr;
- T_{tdi} = 0.8 hr;
- SF_1 = The highest measured, hourly sulfuryl fluoride concentration at 5 feet from the structure (Cochran, 2010) during the first sampling period of the fumigation phase (sampling event #1, House 1, sampling location NW-5 in (Barnekow, 2015)). The actual sampling time was 4.07 hours;

- SF_1 = 2.775 ppm / 4.07 hr = 0.682 ppm.

- SF_o = The highest measured, hourly sulfuryl fluoride concentration at 5 feet from the structure (Cochran, 2010) during the last sampling period of aeration (sampling event #12a, House 3, sampling location E-5 in (Barnekow, 2015)). This sample was <LOD and was replaced by 1/2 LOD before adjustment for field spike recovery. The actual sampling time was 6.8 hours;
  - SF_o = 0.0131 ppm / 6.8 hrs = 0.0019 ppm.
- SF_i = The highest measured, hourly SF concentration in living areas inside the structure during the first 1-hr post-clearance period (Cochran, 2010) (sampling event #13, House 2, location inside 1, in (Barnekow, 2015));
  - SF_i = 0.486 ppm / 1 hr = 0.486 ppm.

[11] Fumigator & clearance crew, seasonal exposure:

- 8-hr TWA = $(T_{fa} * [SF_1] + T_{tdo} * [SF_o] + T_{tdi} * [SF_i]) / 8$ hr, where:
- T_{fa} = 1 hr;
- T_{tdo} = 3 hr;
- T_{tdi} = 1 hr;
- SF_1 = mean measured, hourly SF concentration at 5 feet from the structure during (Cochran, 2010) the first 4 hours of fumigation (sampling event #1, Houses 1-3, in (Barnekow, 2015)). The average duration of sampling event #1 was 4.1 hours;
  - SF_1 = 0.762 ppm / 4.08 hr = 0.187 ppm.
- SF_o = mean measured, hourly SF concentration at 5 feet from the structure (Cochran, 2010) during the last sampling period of aeration (sampling event #12a, Houses 1-3, in (Barnekow, 2015)). All samples were <LOD and were replaced by 1/2 LOD before adjustment for field spike recovery. The average duration of sampling event #12a was 7.7 hours;
  - SF_o = 0.0112 ppm / 7.7 hr = 0.0015 ppm.
- SF_i = mean measured, hourly SF concentration in living areas inside the structure during the first 1-hr post-clearance period (Cochran, 2010) (sampling event #13, Houses 1-3, in (Barnekow, 2015));
  - SF_i = 0.157 ppm / 1 hr = 0.157 ppm.

[12] The highest 24-hr TWA value measured during the first 24 hours of the fumigation phase (0-24 h, sampling events ## 1 thru 4) inside the home adjacent to House 2.

[13] The highest 24-hr TWA value measured during the second 24 hours of the fumigation phase (24-48 h, sampling events ## 5 thru 7) inside the home adjacent to House 2.

[14] The highest 22-hr TWA value measured during the aeration phase (sampling events ## 8 thru 12a) inside the home adjacent to House 2.

[15] The highest first 24-hr TWA of post-clearance (sampling events ## 13 thru 19, sample locations Inside1 thru 3 in House 3). For comparison with data in Beauvais (2013), the average first 24-hr TWA of post-clearance in Houses 1 thru 3 would be 0.62 ppm.

[16] The highest second 24-hr TWA of post-clearance (sampling events ## 20 thru 22, sample locations Inside1 thru 3 in House 3). For comparison with data in Beauvais (2013), the average second 24-hr TWA of post-clearance in Houses 1 thru 3 would be 0.39 ppm.

The structures included in the three DAS studies were single-family homes, multi-unit apartment complexes (3 to 12 residential units), and a multi-level school house (Barnekow and Byrne, 2006; Barnekow, 2010; Barnekow and Rotondaro, 2015). The conclusions in this memorandum and in (Cochran, 2010; Beauvais, 2013) extend only to sulfuryl fluoride fumigations of structures similar to those described above. We did not have data to address fumigations made to other types of structures.

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Attachment

Attachment I

Department of Pesticide Regulation

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Arnold Schwarzenegger
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DATE: May 17, 2010

SUBJECT: REVIEW OF STUDY 242458: SULFURYL FLUORIDE AND CHLOROPICRIN CONCENTRATIONS IN AIR DURING FUMIGATION, AERATION AND POST-CLEARANCE OF RESIDENTIAL STRUCTURES

In response to a Risk Management Directive for sulfuryl fluoride use in structural fumigations (Gosselin, 2007), a study was submitted in which the activities, associated with clearance of structures following fumigation, were changed (Barnekow and Byrne, 2006). This new procedure referred to as the California Aeration Procedure (CAP) has the ventilation stack in place before the structures are fumigated.

Eight California houses were fumigated with sulfuryl fluoride (SF) in conjunction with chloropicrin as a warning agent (Barnekow and Byrne, 2006). Ventilation of the structures was accomplished using a tarpaulin removal and aeration plan (TRAP) modified by the California Aeration Procedure (CAP). (CAP does not require workers to don self-contained breathing apparatus (SCBA) to aerate a structure- as the ventilation equipment are already in place and can be started without entering the structure.)

Dow AgroSciences (DAS) monitored air concentrations of sulfuryl fluoride at various distances (1.5 meters to 30 meters) at locations surrounding the eight fumigation sites. Air samples were collected (1) before fumigation, (2) during fumigation, (3) during aeration, and (4) post-clearance. The duration of sampling varied between 1 – 8 hours. On-site meteorological data (wind speed, wind direction, temperature, humidity, pressure, solar radiation, and rainfall) were recorded at 15-minute intervals. Samples were collected by drawing air through activated charcoal-containing tubes at 100 mL/min for periods up to 4 hours, and 50 mL/min for 8 hour periods of time. The sampling tubes had two chambers, with 800 mg of charcoal in the front and 200 mg in the back portion. Laboratory spikes, field spikes, and storage spikes of known amounts of sulfuryl fluoride were added to tubes to ascertain recoveries. The sulfuryl fluoride was extracted from the activated charcoal with sodium hydroxide, and measured using a fluoride ion selective electrode.

A Fumiscope was used to monitor SF concentrations inside the structures and between the structures and the tarps during the fumigation and aeration periods. Internal, post-clearance air monitoring samples were collected in four 1-hour and four 8-hour intervals for 8 sequential periods for a total of 36 hours of continuous monitoring. The air-sampling locations used during collection of the Fumiscope data were also used for collection sites of the indoor time-weighted average (TWA) air samples. The sampling sites used were the living room, attic space, crawl space, and utility area. The measured average application rate in the study was approximately 20 g/m^3, compared to the label-approved rate for use on drywood termites (10.7 g/m^3). The maximum allowable application rate on the label (for powder-post beetles) is 160 g/m^3.

Field spike recoveries from: a) Ojai, CA (2004), 2 structures, averaged 59%; b) Homeland, CA (2004), 2 structures, averaged 68%; c) Reedley, CA (2004), 2 structures, averaged 81.4%; and d) Reedley, CA (2005), 2 structures, averaged 81.7%. The individual and highest measured air concentrations of sulfuryl fluoride during the different phases at five feet from the fumigated structures are shown in Table 1.

Table 1. The individual and highest measured SF concentrations at 5 feet from the fumigated structures during the fumigation and aeration phases.

Location	Fumigation Phase		Aeration Phase	
	Individual Meas.[a] (ppm)	Highest Value[a] (ppm)	Individual Meas.[b] (ppm)	Highest Value[b] (ppm)
Ojai 1 (2004)	1.25	1.25	0.03	0.04
	0.63		0.04	
	0.28		0.03	
	0.23		0.04	
	0.80		0.04	
	0.93		0.04	
	0.28		0.04	
	0.26		0.03	
	1.25		0.03	
Ojai 2 (2004)	0.67	1.43	0.06	0.06
	1.43		0.04	
	0.38		0.04	
	0.26		0.03	
	0.93		0.05	
	0.64		0.04	
	0.19		0.02	
	0.17		0.03	
	0.67		0.06	

Table 1- Continued.

Location	Fumigation Phase		Aeration Phase	
	Individual Meas.[a] (ppm)	Highest Value[a] (ppm)	Individual Meas.[b] (ppm)	Highest Value[b] (ppm)
Homeland 1 (2004)	0.66	2.73	0.02	0.05
	1.88		0.03	
	0.78		0.03	
	0.99		0.04	
	2.73		0.02	
	2.69		0.02	
	0.44		0.05	
	1.16		0.02	
	0.66		0.02	
Homeland 3 (2004)	0.21	1.41	0.03	0.18
	0.26		0.01	
	0.93		0.02	
	0.28		0.08	
	0.56		0.02	
	1.41		0.02	
	0.35		0.02	
	0.47		0.18	
	0.21		0.03	
Reedly 1 (2004)	0.21	1.41	0.02	0.11
	0.26		0.02	
	0.93		0.06	
	0.28		0.05	
	0.56		0.02	
	1.41		0.04	
	0.35		0.05	
	0.47		0.11	
	0.21		0.02	
Reedly 2 (2004)	0.21	0.75	0.03	0.13
	0.31		0.03	
	0.36		0.04	
	0.15		0.07	
	0.61		0.03	
	0.75		0.03	
	0.22		0.13	
	0.67		0.04	

Table 1- Continued.

Location	Fumigation Phase		Aeration Phase	
	Individual Meas.[a] (ppm)	Highest Value[a] (ppm)	Individual Meas.[b] (ppm)	Highest Value[b] (ppm)
Reedly 1 (2005)	0.31	0.34	0.01	0.06
	0.20		0.01	
	0.15		0.01	
	0.34		0.06	
	0.10		0.01	
	0.07		0.01	
	0.08		0.01	
	0.11		0.01	
Reedly 2 (2005)	0.38	0.54	0.01	0.08
	0.50		0.01	
	0.54		0.03	
	0.34		0.08	
	0.16		0.01	
	0.11		0.01	
	0.11		0.02	
	0.05		0.01	

a/ 20 hr time weighted average (TWA) SF concentrations from the study corrected for field spike recoveries.
b/ 24 hr TWA SF concentrations from the study corrected for field spike recoveries.

Ordinarily, WH&S calculates the 95th percentile to estimate an upper-bound acute exposures to fumigants. This statistical approach assumes that each sampling station has an equal probability for capturing an unbiased sample of SF. However, outdoor air movement, such as breezes, can bias the samples. Consequently, in this evaluation the highest measured air concentration of SF at 5 feet was used to as the upper-bound SF concentration.

Indoors, the average air concentration in the 8 structures during the first 12 hours post clearance was 0.7 µg/L. This value could be higher or lower depending upon the application rate used, the degree of compartmentalization and materials used in construction of the structure, and the amount of post-clearance ventilation. Adjusting the study value for the highest application rate (160 g/m3), assuming linearity, the average value would be 5.6 µg/L . The 20-hr TWA for the first day after clearance in the study was 0.61 µg/L. At the highest application rate it would be 4.88 µg/L. Both of these sulfuryl fluoride air concentration are above the reference concentration (0.51 µg/L) for residents and bystanders mentioned in the mitigation memo (Gosselin, 2007). Consequently, entrance into a treated structure should not be allowed until 24 hours after clearance. The average value (0.28 µg/L; 24-hr TWA) during the second 24 hour period (post-clearance) at the study rate is less than the reference concentration (0.51 µg/L) for

residents and bystanders mentioned in the mitigation memo (Gosselin, 2007). At the maximum application rate, assuming linearity, it would be 1.1 µg/L, which again exceeds the reference concentration mentioned in the mitigation memo.

Worker Exposures

The study (Barnekow and Byrne, 2006) does not provide any new, measurements of air concentrations of sulfuryl fluoride collected in the worker's breathing zones. However, the ambient air measurements sulfuryl fluoride, inside and outside the treated homes, can be used as an indication of the air concentrations of sulfuryl fluoride that workers might respire on the job.

The exposure estimates for fumigators and tent crew workers (as described in the Exposure Assessment Document [EAD]) were derived from personal air sampling conducted during task-specific activities as follows:

- Fumigant introduction, period during which a fumigator released gas into a structure.
- Opening structure to initiate aeration, period during which a fumigator placed ventilation fans and opened doors and windows of a structure.
- Removal of ground snakes, period during which workers removed snakes, i.e., water or sand filled bags used to weigh down the tarpaulin to form a seal at the base of the structure.
- Opening of ground seams, period during which workers unclamped tarpaulin at ground level.
- Opening of roof seams, period during which workers unclamped tarpaulin on the roof.
- Structure closing after the first 1 hour of aeration, period during which a fumigator closed windows and locked doors of a structure at the end of the minimum active aeration period. The crew leaves the site sealed during the remainder of the 6- or 8-hour minimum aeration period. In typical practice, the fumigator returns the next day to test the structure for clearance.
- Tarpaulin folding, period during which workers rolled and folded tarpaulin removed from the treated structure after the initiation of aeration.
- General detarping, period from arrival at a site following the treatment period (average 25 hr) to the end of detarping. General detarping scenario represents the total potential daily exposure a tent crew worker may experience from activities including removing ground snakes, opening roof and ground seams, tarp folding and general clean-up.
- Testing for clearance, period during which a fumigator entered a treated structure to test for clearance at the end of the minimum aeration period. In this study, all California fumigators tested for clearance the day following the initiation of aeration.

The CAP technique results in a major reduction in the number of tasks associated with exposure to sulfuryl fluoride. The licensed fumigator will still make the application of the fumigant,

which is approximately 20 pounds in an average house of 30,000 ft^3 (10.7 g/m^3). At a rate of 3 lb/min, this will take a little over 6 minutes. The rest of the time, fumigators are involved with the same activities as the tent crew. The tent crew activities are now limited to a) putting the tarps in place prior to fumigation, b) checking the efficacy of the seal using the warning agent as an indicator, c) and a general detarping scenario after aeration in which ground snakes are removed, the roof and ground seams are opened, the tarp is removed, folded, and involvement with a general clean-up of a site.

In estimating exposures, we assumed that, on average, a fumigation crew will deal with 2-3 treatment sites/day. However, during the seasonal peak of activity, a crew could be involved with as many as 4-5 sites in a day. This latter level of activity would likely be 10 hours in duration, distributed between the five work sites. Another couple of hours would likely be spent driving between the sites. Thus, on an acute basis, it would be possible for a licensed fumigator to treat up to five structures for a total of 10 hours on site. As indicated above, the introduction of SF into the structure ordinarily takes just a few minutes. Respiratory protection is not specifically required by the label during the introduction of the fumigant. The fumigator would then be involved in dismantling the tanks and hoses used for the introduction of SF, and loading them on a truck to go to the next site. Although most of the checking for leaks takes place before the SF is introduced into the structure, the fumigator would likely make a last check of the perimeter before leaving the site. Thus, the total time on-site at each location where SF is introduced to a structure would be 2 hours, but 30 minutes at each site could reasonably be expected to involve exposure to SF. In this study, the highest measured 1-hr time-weighted-average (TWA) air concentration of SF at 5 feet from the structures during the initial fumigation period was 4.1 ppm, with an average 1-hr TWA of 0.56 ppm. These values could be higher or lower depending upon the application rate used. Approximately 3% of all fumigations are conducted at the label recommended rate (160 g/m^3) for powder post beetles, mostly in Northern California. Most fumigations are conducted for dry-wood termites (10.7 g/m^3) at about ½ the rate used in the study (20 g/m^3) (Barnekow and Byrne, 2006).

The greatest exposure of the tent crew would be expected to encounter would occur during take-down procedures. Again, assuming a maximum of 5 structures could be fumigated in a given day, take-downs could take place for 2 hours at each of those structures. It was also assumed that 3/4 of the take-down time would be spent doing finishing activities around the exterior of the homes, and 1/4 of the time retrieving equipment from the interior of the structures. Inside time would also be spent taking measurements of the interior to certify clearance of the SF had been achieved.

The highest measured 8-hr TWA air concentration of SF at five feet from the exterior of the homes at the finish of the aeration process was 0.073 ppm, with an average value of 0.017 ppm in this study. These are the concentrations that were used to simulate SF exposure for workers during outside activities. Inside the homes, the highest measured value at sampling stations in

living areas during the first hour after clearance was declared was 1.66 ppm, with an average of 0.66 ppm. These values could be higher or lower depending upon the application rate used. It should be noted that SF concentrations under 1 ppm are required before a declaration of "clearance" can be made. Apparently, the real-time monitoring of SF concentrations was inaccurate.

An estimate of the reasonable, worst-case fumigators' acute exposures on-site using the CAP method was made using the following equation:

$$\text{10-hr TWA} = (T_{fa} * [SF_1])/10$$

Where: 10-hr TWA = the acute air concentration of sulfuryl fluoride for a 10-hr on-site workday.
T_{fa} = Time spent in activities during the fumigation phase (2.5 hr)
SF_1 = Highest measured sulfuryl fluoride concentration at 5 feet during the first hour of fumigation (4.1 ppm)

These numbers were derived from a study conducted at an average application rate of 20 g/m^3, . The values could be higher or lower depending upon the application rate used.

Chronic exposures can be calculated using the same equation, but the times of exposure have to be adjusted to match the time spent treating an average of 2 homes/day ($T_{fa} = 1$). Also, the sulfuryl fluoride concentrations used in the calculation will be the average measured air concentrations of SF ($SF_1 = 0.56$). It should be noted that the on-site repetitive exposure time is only 4 hours.

An estimate of the reasonable worst-case tent crew members' acute exposure on-site using the CAP method was made using the following equation:

$$\text{10-hr TWA} = (T_{tdo} * [SF_o] + T_{tdi} * [SF_i])/10 \text{ hr}$$

Where: 10-hr TWA = The acute air concentration of sulfuryl fluoride for a 10-hr on-site workday.
T_{ido} = Time spent in take-down activities outside the fumigated structures (7.5 hr)
SF_o = Highest measured, hourly sulfuryl fluoride concentration at 5 feet during the last 8 hours of aeration. (0.073 ppm)
T_{tdi} = Time spent removing equipment from inside the structure after aeration (2.5 hr)
SF_i = Highest measured hourly SF concentration in living areas inside a structure during the first hour after aeration (1.66 ppm)

These numbers were derived from a study conducted at an average application rate of 20 g/m^3. The values could be higher or lower depending upon the application rate used.

Chronic exposures can be calculated using the same equation, but the times of exposure have to be adjusted to match the time spent treating an average of 2 homes/day (T_{ido} = 3; T_{idi} = 1). Also, the sulfuryl fluoride concentrations used in the calculation will be the average measured air concentrations of SF (SF_o = 0.017; SF_i = 0.66). These values could be higher or lower depending upon the application rate used. It should also be noted that the on-site repetitive exposure time is assumed to be only 4 hours.

Acute exposures for licensed fumigators involved in both set-up and take-down at 5 sites can be estimated using the following equation and the assumption that the fumigator will be present at 3 sites at the start of the fumigations, and 2 sites that will be cleared.

$$\text{10-hr TWA} = (T_{fa} * [SF_1] + T_{tdo} * [SF_o] + T_{tdi} * [SF_i])/10 \text{ hr}$$

Where: 10-hr TWA = the acute air concentration of sulfuryl fluoride for a 10-hr on-site work day.

T_{fa} = Time spent in activities during the fumigation phase (1.5 hr)

SF_1 = Highest measured sulfuryl fluoride concentration at 5 feet during the first hour of fumigation (4.1 ppm)

T_{ido} = Time spent in take-down activities outside the fumigated structures (3 hr)

SF_o = Highest measured, hourly sulfuryl fluoride concentration at 5 feet during the last 8 hours of aeration. (0.073 ppm)

T_{tdi} = Time spent removing equipment from inside the structure after aeration (1 hr)

SF_i = Highest measured hourly SF concentration in living areas inside the structure during the first hour after aeration (1.66 ppm)

These numbers were derived from a study conducted at an average application rate of 20 g/m^3. The values could be higher or lower depending upon the application rate used.

Chronic exposures can be calculated using the same equation, but the times of exposure have to be adjusted to match the time spent treating an average of 2 homes/day (T_{fa} = 0.5; T_{ido} = 1.5; T_{idi} = 0.5). It was assumed that the fumigator would fumigate one structure and assist in the take-down activities at a second structure. Also, the sulfuryl fluoride concentrations used in the calculation will be the average measured air concentrations of SF (SF_1 = 0.56; SF_o = 0.017; SF_i = 0.66). These values could be higher or lower depending upon the application rate used. It should also be noted that the on-site repetitive exposure time is only 4 hours. The results of the above calculations are shown in Table 2.

Table 2. Estimated acute and long-term exposures to sulfuryl fluoride for handlers, based on measured air concentrations of SF (Barnekow and Byrne, 2006).

Work Category	Unadjusted Acute 10-hr TWA[a] (ppm)	Adjusted Acute 10-hr TWA[b] (ppm)	Chronic 4-hr TWA[c] (ppm)
Fumigators	1.025	8.20	0..14
Tent Crew	0.470	3.76	0.22
Fumigator + clearance activity[d]	0.803	6.42	0.16

a/ The acute, 10-hr, on-site, time-weighted-average exposure of handlers (fumigators and tent crew) based on an upper-bound fumigation activity involving 5 structures conducted at 20 g/m^3.

b/ The adjusted, acute, 10-hr, on-site, time-weighted-average exposure of handlers (fumigators and tent crew) based on an upper-bound fumigation activity involving 5 structures conducted at 160 g/m^3 (the maximum label-approved rate of SF structural application).

c// The chronic, 4-hr, on-site, time weighted-average exposure of handlers, based on an estimated average of 2 structures being treated each day.

d/ Acute exposure assumes fumigator treats 3 homes and is involved in the take-down activities of two homes. On average, it was assumed that the fumigator treats one structure and is involved in take-down activities at a second home.

In the risk mitigation memo (Gosselin, 2007), it states that "…mitigation efforts should ensure that acute exposures to sulfuryl fluoride do not exceed the 24-hour time-weighted average (24-hr TWA) reference concentrations of 2.57 ppm …for workers…"; and "The 24hr TWA reference concentrations for repetitive exposures for workers are 0.48 ppm (1-2 weeks), 0.14 ppm (seasonal), and 0.04 ppm (chronic)".

The acute 10-hr on-site TWAs in Table 2 need to be adjusted to 24-hr TWAs by multiplying those values by 10/24. Thus, the acute 24-hr TWAs from the study for fumigators, tent crew, and fumigators also doing clearance activity are 0.43 ppm, 0.20 ppm, and 0.33 ppm, respectively. At the highest label-approved application rate, the acute 24-hr TWAs are 3.42 ppm, 1.57 ppm, and 2.68 ppm, respectively. Consequently, acute exposures for fumigators and fumigators performing tent-crew activities at the highest, label-approved rate exceed the acute mitigation value (2.57 ppm) proposed in the memo.

The repetitive , 4-hr on-site TWAs in Table 2, likewise need to be adjusted to 24-hr TWAs by multiplying those values by 4/24. Thus, the repetitive 24-hr TWAs at the average application rate for fumigators, tent crew, and fumigators also doing clearance activity are 0.03 ppm, 0.04

ppm, and 0.03 ppm, respectively. Consequently, the estimate of repetitive exposures for all workers at the average application rate of this study are equal to, or less than the chronic mitigation value (0.04 ppm) proposed in the memo.

References:

Barnekow, D. E., and S.L. Byrne, 2006. Sulfuryl fluoride and chloropicrin concentrations in air during fumigation, aeration and post clearance of residential structures. Dow AgroSciences Study #040099. DPR Vol. 50223-0091 Record # 242458.

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